Universität Stuttgart
IER Institut für Energiewirtschaft und Rationelle Energieanwendung

Round Robin Testing for the Development of Guidelines to Measure Efficiency of Packaged Air Compressors

Energy Efficiency in Motor Systems (EEMODS), Lucerne Switzerland, 3.-5. September 2024

Peter Radgen

With the Support of
swissenergy
4E Electric Motor Systems Platform EMSA

Framework for Air Compressors
Background

- Motor Driven Systems Account for the Mayor Share of Electricity in Consumption in Industry
- Energy Efficiency in Motor Driven System have proven to be an cost effective means to reduce electricity consumption and therefore also Green House Gas Emissions from the Power Sector
- Efficiency Regulation around the World started with electric motors and expanded into the main motor driven systems, Pumps and Fans.
- MEPS Regulation for Motors, Pumps and Fans had been introduced in the most relevant jurisdictions together with standards setting the rules and approaches for efficiency classification and testing.
- Standard Air Compressors had been in the focus as other motor driven system, but efficiency regulation and standards for efficiency testing is running behind for air compressors.
- US and China has MEPS for air compressors in place but with low level of ambition. EC has decided to postpone introduction of MEPS for Air Compressors.

Air Compressor Efficiency Testing

Universität Stuttgart
IER Institut für Energiewirtschaft und Rationelle Energieanwendung

- International standard for air compressor testing is **ISO 1217 Displacement compressors - Acceptance tests**
- It´s aim is not to regulate energy efficiency but to set out an common approach to test compressors to contractual agreements made between the customer and the manufacturer.
- The standard was **last revised in 2009** and an amendment was added in 2016 on the “calculation of the isentropic efficiency and relationship with specific energy”.


INTERNATIONAL STANDARD

ISO 1217

Fourth edition
2009-07-01

Displacement compressors — Acceptance tests

Compresseurs volumétriques — Essais de réception

- The **difficulties to use the standard to measure energy efficiency** of packaged air compressors became obvious in the framework of the Ecodesign discussions for standard air compressors at the European Level. The US has added additional test requirements in the MEPS legislation to cope with.
- Note: In 2024 ISO TC118 decided to revise the standard in the coming years.

Testing of Packaged Air Compressors

Identifying challenges, weaknesses and improvement potentials

Universität Stuttgart
IER Institut für Energiewirtschaft und Rationelle Energieanwendung

- Testing Air Compressor Efficiency **of the same Compressor** in three different laboratories around the word (Germany, Denmark, Australia).
- Transpose the ISO 1217 standard in a testing approach and laboratory set up for testing.
- **Analyse and compare the results of the testing in the three laboratories.** The aim was not to prove the efficiency of the compressor tested.
- Develop guidelines for the understanding of the requirements from the standard, closing gaps left open or not clearly defined in the standard
- Make proposals for improvements and updates of the standard

Technical Data of Tested Air Compressors

Universität Stuttgart
IER Institut für Energiewirtschaft und Rationelle Energieanwendung

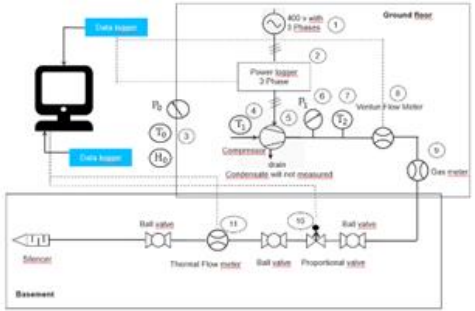
Type	Oil injected air cooled screw compressors	
Rated power	4 kW	5.5 kW
Max. working pressure (absolute)	9 bar	12 bar
Operating pressure (absolute)	8.5 bar	11 bar
Rated volume flow at operating pressure	0.6 m^3/min	0.78 m^3/min
Rated motor speed	2910 rpm	2950 rpm
Frequency	50 Hz	50 Hz
Voltage	400 V	400 V
Full load current	8.1 A	12 A

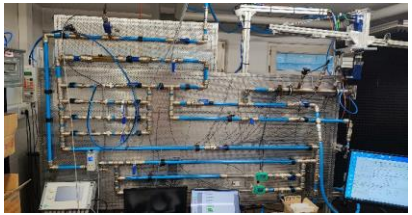
Laboratory Set Up

IER Germany and DTI Denmark

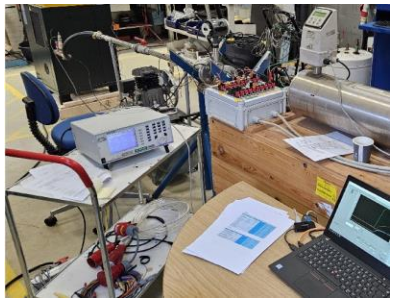
Universität Stuttgart
IER Institut für Energiewirtschaft und Rationelle Energieanwendung

IER, Germany





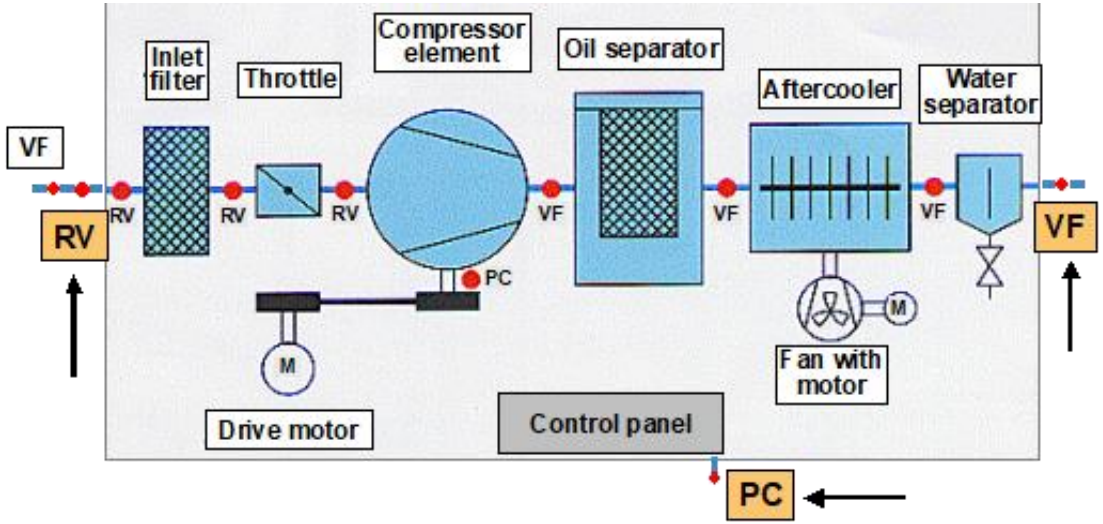
DTI, Denmark



- 2 compressors tested at manufacturer and in three different laboratories
- Measurement set up had been different in all laboratories

Key Measurement Points for Packaged Air Compressors

ISO 1217 Annex C



- Compressor has to be treated as **complete unit**.
- If a refrigeration dryer is integrated in the package the consumption of the **dryer is part of the package consumption.** However ISO 1217 gives no indication if dryer should be in operation, idle or off mode.

PC = Power consumption

VF = Volume flow rate

RV = Reference point volume flow rate

Source: Compressed Air Fact 04 Production. Compressed air campaign „druckluft effizient“, Karlsruhe, Frankfurt, Berlin, October, 2003.
http://druckluft-effizient.de/wp-content/uploads/2020/09/04-production.pdf

Volume Flow Measurement Technology

The most crucial part in testing

- Different types of flow meters available on the market (thermal, vortex, orifice plate/nozzle, Coriolis, ultrasonic (inline/clamp on), bellow gas meter.
- Meters require about 20xD straight inlet pipe
- Flow straighteners might enable shorter length
- Accuracy between 0.5 to 5 % depending on type and manufacturer
- Pressure loss important for continuous measurements in compressed air systems
- Dynamic range typically from 1:10 to 1:250
- Price from ~~€€€€~~ to ~~€€€€€€~~ depending on size
- Direct mass flow metering possible only with Coriolis. Other require additional pressure and temperature sensor and an arithmetic unit

Suitable meters for ISO 1217 should fulfil the following conditions

- Insensitive to water droplets /high humidity and particles
- High accuracy
- Having sufficient inlet and outlet piping to ensure uniform flow

Most suited for ISO 1217 testing are bellow gas and coriolis flow meters

Variety of Standard Conditions for Volume Flow

Confusing Standard Conditions

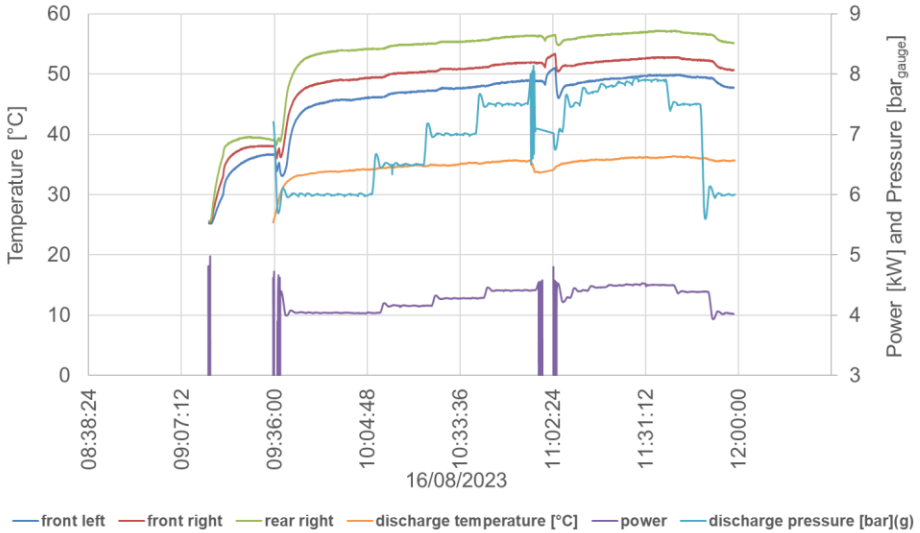
Universität Stuttgart
IER Institut für Energiewirtschaft und Rationelle Energieanwendung

Standard	Temperature	Pressure	Relative humidity	Density
	[°C]	[bar_{abs}]	[%]	[kg/m³]
DIN ISO 2533: 2018	15	1.01325	0	1.225
ISO 8778: 2003	20	1.00000	65	
DIN 1945-1: 1980	20	1.00000	0	
DIN 1343: 1990	0	1.01325	0	
ISO 1217: 2009 Annex F (informative, reference standard inlet condition)	20	1.00000	0	

Test Excecution

Universität Stuttgart
IER Institut für Energiewirtschaft und Rationelle Energieanwendung

- ISO 1217 requires stale operation conditions but does not specify how this is defined
- Compressor performance changes significantly during the warm up period, therefore we recommend at least 30 minutes full load operation before testing starts.



- Testing of compressor to be performed not only at a single pressure, but over a number of pressure points including the maximum pressure and in during idling. However without overwriting data in the control system, tests at maximum pressure is impossible, as compressor automatically unloads, if maximum pressure is reached.

Measurement Results from the testing

5.5 kW Compressor @operating pressure

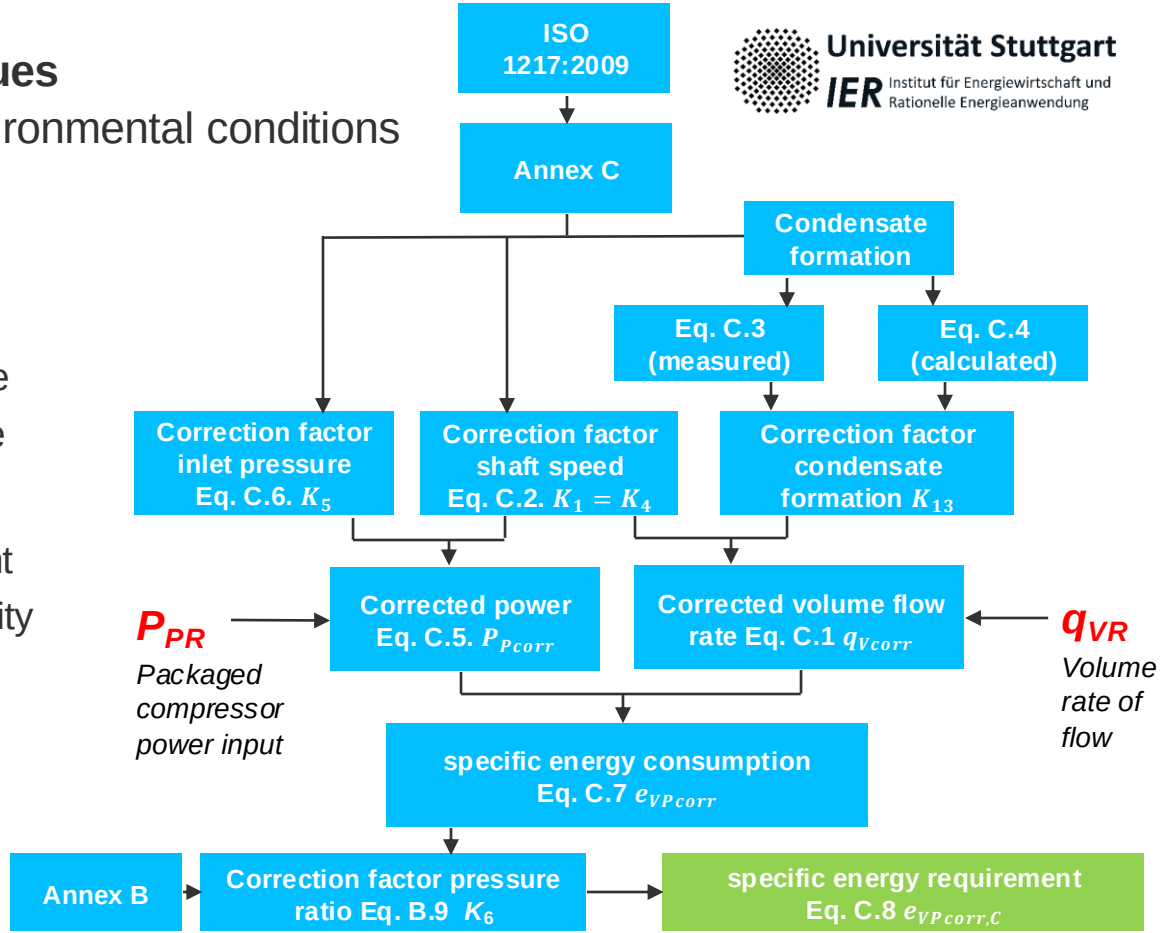
Description	Data point measured	Unit	Test@IER	Test@DTI	Test@Manufacturer
Ambient pressure	P_0	bar $_{abs}$	0.969	1.014	0.987
Inlet pressure	P_1	bar $_{abs}$	0.969	1.014	0.987
Discharge pressure	P_2	bar $_{abs}$	11	11	11
Inlet Temperature	T_1	°C	26.48	21.43	21.90
Discharge Temperature	T_2	°C	29.58	22.90	24.40
Power Consumption	P_{PR}	kW	6.562	6.791	6.752
Volume flow (p_2, T_2)	q_{VR}	m^3/min	0.741	0.703	0.781

ISO 1217 does not indicate, if meter readings should be a single reading or an averaging of readings over a certain time and or a dedicated number of readings.
In the three labs an automatic data acquisition system was used to collect the readings. Values are therefore average readings.

Correction of Meassured Values

Compensating for different environmental conditions

- ISO 1217 includes a number of procedures for recalculation of the measured values into comparable values.
- Key correction factors are ambient temperature, pressure and humidity and shaft speed.



Corrected Results From Compressor Testing

Universität Stuttgart
IER Institut für Energiewirtschaft und Rationelle Energieanwendung

Description	Data point calculated	Unit	Test @IER	Test@DTI	Test@Manufacturer
Isentropic Power	P_{isen}	kW	4.226	4.060	4.458
Corrected Power	P_{Pcorr}	kW	6.772	6.787	6.842
Corrected Volume Flow Rate	q_{Vcorr}	m³/min	0.746	0.703	0.781
Correction factor for inlet pressure	K_5	-	1.032	0.999	1.013
Correction factor for condensate formation	K_{13}	-	1.006	1.010	1.000
Specific energy requirement	e_{VPcorr}	kW/(m³/min)	9.076	9.655	8.759
Isentropic Efficiency η_{isen}		%	62.4	59.8	65.1

The specific energy requirement e_{VPcorr} ranges from 8.76 kW/(m³/min) to 9.66 kW/(m³/min), a difference of 0.9 kW/(m³/min) or about 10%.
The calculated isentropic efficiency is in the range from 59.8 to 65.1 %, a difference of up to 5.3%-points or 8%.

Summary and Conclusions

Universität Stuttgart
IER Institut für Energiewirtschaft und Rationelle Energieanwendung

- Testing results in the different laboratories have shown differences in results broader than expected.
- Impact factors for deviating results can be versatile. Possible factors include:
  - Different flow meter technologies used (manufacturer (bellow gas meter), IER (nozzle flow meter), DTI (Coriolis))
  - Different voltage levels in power supply, non-uniform three phase current
  - Condensate formation and humidity of inlet air
  - Differences in recalculation of volume flow to standard conditions
- **Conclusions from testing**
  - Procedures in ISO 1217 standard to be improved and measurement procedures and equipment to be more precisely specified
  - Ongoing verification process of measurement equipment used and procedures for calculation applied
  - Further testing with a different setting would enhance further understanding of possible effects.
  - Shipping compressors around the world is expensive and comes with significant administrative burdens

Acknowledgements

- Thanks to the rest of the team that collaborated on this project, especially Sandie B. Nielsen (DTI, DK), Maarten van Werkhoven (TPA Advisor, NL), Alireza Hojjati (IER,DE) and Andrew Baghurst (Caltest, AU).
- Thanks to the partners which have invested more time and money than originally planed to better understand the challenges and possible solutions.
- Special thanks to Swiss Energy and EMSA and the Australian Government for financial support of the project
- Thanks to the compressor manufacturer who supported the project by providing two compressors for testing and took care for the logistics and export documents.

Universität Stuttgart

Thank You !

E-Mail peter.radgen@ier.uni-stuttgart.de
Fon +49 (0) 711 685-87877

University of Stuttgart
Institut Energy Economics and Rational Energy Use (IER)
Heßbrühlstr. 49a
70565 Stuttgart
Germany